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Development of Wireless Sensor Node for Landslide Detection

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***Abstract*— Landslides have frequently occurred on natural slopes during periods of intense rainfall. With a rapidly increasing population on or near steep terrain in Korea, landslides have become one of the most significant natural hazards. Thus, it is necessary to protect people from landslides and to minimize the damage of houses, roads and other facilities. To accomplish this goal, many landslide prediction methods have been developed around the world. In this study, a prototype of landslide detection is introduced. This system is based on the wireless sensor network (WSN) that is composed of sensor nodes, gateway, and server system. Sensor nodes comprising sensing and communication part are implemented to detect ground movement. A sensing part is designed to measure inclination angle and acceleration accurately, and a communication part is deployed with Bluetooth (IEEE 802.15.1) module to transmit the data to the gateway. To verify the feasibility of this landslide prediction system, a series of experimental studies was performed at a small-scale earth slope equipped with an artificial rainfall dropping device. It is found that sensing nodes planted at slope can detect the ground motion when the slope starts to move. It is expected that the prototype of landslide detection can provide early warnings when landslides occurs.**

***Index Terms*—debris flow, disaster management, landslide detection, wireless sensor node, wireless sensor network**

I. Introduction

Landslides are a serious geological hazard caused when masses of rock, earth and debris flow down a steep slope during periods of intense rainfall and rapid snow melt. It is reported that landslides happen more repeatedly than before and their damages are increasing due to global warming [1]. Every year, landslides occur at natural slopes in Korea, resulting in loss of human life, destruction of houses and facilities, damage to roads, rail lines and pipelines, vehicle accidents and train derailments, damage to agricultural land, livestock, and forest stands, and many other losses. In order to prevent landslide, hill slopes that are unstable should be strengthened. To mitigate its damage, a system that can predict the occurrence of a landslide at a specific site is required. The immediate detection of landslide activity provided by real-time systems can be crucial in saving human lives and protecting property. The continuous data provided by remote real-time monitoring permits a better understanding of dynamic landslide behavior that enables engineers to create more effective designs to prevent or halt landslides. In this study, a prototype of landslide detection is introduced. This is based on wireless sensor network and designed to detect debris flows that is frequently occur in Korea [2]. To verify the feasibility of this landslide prediction system, a series of experimental studies was performed at a small-scale earth slope increasing soil moisture content. It is found that sensing nodes planted at the slope can detect the ground motion when the slope starts to move. It is expected that the landslide prediction system by wireless senor network will provide early warnings when landslides such as debris flow occurs.

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II. Debris Flow Instrumentation

A. *Sensing debris flow preceding events*

Most debris flows are triggered by intense rainfall or rapid snowmelt, therefore monitoring hydrologic conditions can provide advance knowledge of hazardous conditions. Precipitation is often an essential parameter of interest for warning application. After precipitation infiltrates the soil surface, it moves through the soil as both unsaturated and saturated subsurface flow. A variety of instrumentation may be used to monitor subsurface hydrologic conditions that occur prior to debris flow initiation. Most soils that are susceptible to mobilization into debris flows have relatively high permeability and therefore the use of standpipe or Casagrande piezometers with small diameters are preferred. Time domain reflectometry (TDR) that has been recently developed to measure soil moisture and earth deformation can be also used [3].

For reliable debris flow warning systems, it is not enough to only detect debris flow occurrence. Therefore it is essential to sense complementary parameters that can confirm hazardous conditions and help prevent false alarms. In addition to the hydrologic monitoring, ground deformation measurements are desired. Cable extensometers can be used to measure extension or contraction across tension cracks. They can also be mounted with a cable extended down a borehole and through the failure zone to stable ground beneath a slide. Inclinometers can be also used to make intermittent or manual measurements of a minor deformation of a plastic or aluminum casing that is installed in a borehole [4]. Alternatively, tilt meters can be permanently installed to make continuous measurements. Recently, ground deformation can also be intermittently or continuously measured using geospatial positioning systems (GPS) [5].

B. Measuring debris flow dynamics

Installation and maintenance of sensors that require contact or close proximity to unstable steep slopes where debris flows may occur are dangerous. Alternatively, sensors that can detect debris flow occurrence and do not require close proximity to the area are preferred for long-term reliable operation [5]. To detect and monitor debris flows, the Acoustic Flow Monitor (AFM) was designed by the U.S. Geological Survey Cascades Volcano Observatory. It has been successfully used internationally as part of real-time warning systems in valleys threatened by such flows. The AFM system has also been proven to be an effective tool for monitoring debris flows [6].

Where debris flow is channelized and it is possible to install an overhead boom or cable, distance between a range finder and the flow surface can be sensed. Ultrasonic range finders, also known as distance meters, can measure distances up to 20m or more by emitting ultrasonic or microwave bursts and measuring the round-trip travel time of the emissions that reflect back off the flow surface. Another method utilizes surface velocity sensing with Doppler radar, and this method is similar to ultrasonic range finders. Video cameras and recorders have also been used to record debris flows [5].

C. Features of traditional measuring methods

The assessment of debris flow can be usually undertaken by means of monitoring. The measurement of superficial displacement is the simplest way to observe the evolution of debris flows and to analyze the kinetics of the movement. A variety of surveying techniques have been used to track the superficial movements of unstable areas. Conventionally, tapes and wire devices have been used to measure changes in distance between points. Levels, theodolites, and total station measurements provide the coordinates and changes of target by which the ground motion can be detected [7].

As discussed previously, various prediction sensors have been proposed such as multi-point borehole extensometer, tilt sensors, displacement sensors, and volumetric soil water content sensors. Most of these sensors, however, require drilling 20-30 meter holes into the surface, making the installation very expensive and requiring skilled labor. Furthermore, these are expensive sensors, making wide scale deployment infeasible. Installing a single sensor for monitoring an entire hill side is not sufficient as the properties of the ground change every 100-200 meters. Wiring each sensor to a central data logger is also not feasible in the steep terrain because it requires high maintenance, and is subjected to a single point of failure [8]. In addition, the locations where the data gathering will take place lack electrical and communication infrastructure, making conventional monitoring systems that rely on power grids and wired communication links inappropriate. To solve these problems, emerging technologies to develop landslide monitoring system by wireless sensor network are being studied vigorously throughout the world [8-9].

III. IMPLEMENT OF WIRELESS SENSOR NODE

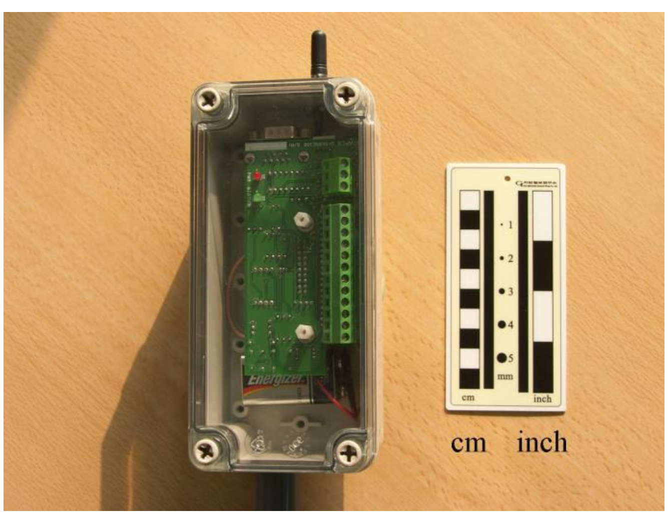
A. Wireless Sensor Network (WSN)

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions, such as light, temperature, sound, vibration, pressure, motion or pollutants, at different locations. In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and a power supply, usually a battery. It is anticipated that aggregating sensors into sophisticated computation and communication infrastructures, called wireless sensor networks, will have a significant impact on a wide range applications such as combat field surveillance, intrusion detection, disaster management, structural health monitoring, asset monitoring, and environmental monitoring. The fundamental goal of a wireless sensor network is to produce global information from local data obtained by individual sensors. WSN processes data gathered by multiple sensors to monitor events in an area of interest [10]. By combining sensed data from a large number of distributed sensors, a global monitoring can be performed. This point is a major difference compared with traditional monitoring methods which depend on existing fixed single sensors [8].

The WSN can be divided into three major parts; sensor nodes, the gateway and the server system. Sensors are generally equipped with data processing and communication capabilities. The sensing circuitry measures parameters from the environment surrounding the sensor and transforms them into electric signals. Sensor nodes composed of sensing part and communication part send collected data, usually via radio transmitter, to a gateway (a base station or sink node). In general, the sensing circuitry generates analog signals, and therefore these signals are sampled using A/D converter and stored in the on-board memory as a sequence of digital values. The sensed data can be further processed using data processor (microprocessor) prior to sending them over to the base station [10]. Wireless sensor nodes are mainly to encode and encapsulate the measured parameters, then to transmit them to the gateway via wireless link. Currently available sensors employ one of the following types of radios. The simplest alternative is to use a free band (315/433/868/916 MHz) which has a bandwidth in the range 20-50 kbps. Another models support an IEEE 802.15.1 (Bluetooth) or 802.15.4 (ZigBee) radio operating in the 2.4 GHz band. The radio range varies with a maximum of about 300m (outdoor) for the first radio type, 30m for the IEEE 802.15.1 radio, and 125m for 802.15.4 radios. The gateway is responsible for polling sensor nodes regularly to acquire and record the relevant data [11-12]. The server system gathers relevant hydrological and geological data via Internet from the threatened region where the landslides are likely to occur. The server system has to fulfill extracting and displaying relevant information to assist authorities to make decisions, and furthermore generating alert or alarm signals if certain thresholds are reached or exceeded. Since the implementation of an alert service is very important for hazard monitoring, such a service may, in general, need the development of intelligent software for evaluating all the measurements from different sensors against predefined thresholds [13].

B. Development of landslide detection sensor

A debris flow involves gravity-driven motion of solid-fluid mixtures with abrupt surge fronts, free upper surfaces, variably erodible basal surfaces, and compositions that may change with position and time. When a debris flow initiates, the rapid initial landslide may continue downslope without confinement. In granular materials this always leads to disintegration, producing flow-like motion [5]. In order to detect such a ground movement, a sensor node based on wireless communication is developed. The sensor node combines a sensing element, or transducer, with A/D conversion, signal processing, memory, radio-frequency communication and battery power supply. For the landslide detection, a low-g (±1g range) ADXL 202 biaxial accelerometer is used (http://www.analog.com). The inclination angle can be obtained from the predefined relationship between inclination angle and acceleration. The sensor node and the view of PCB are shown in Figures 1a and 1b, respectively.



(a)

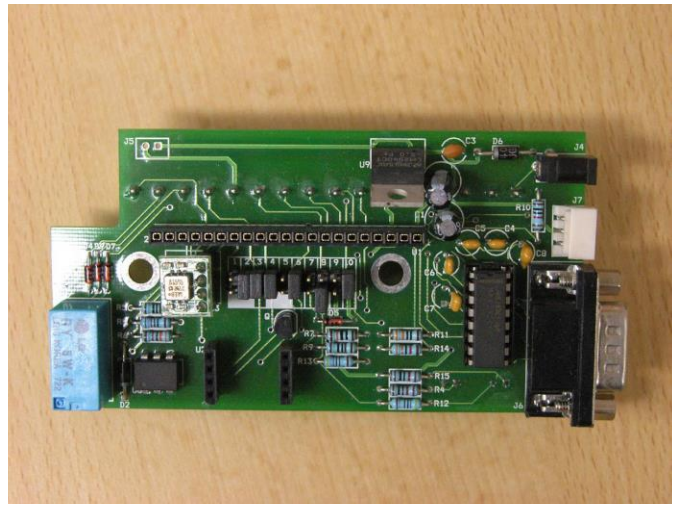


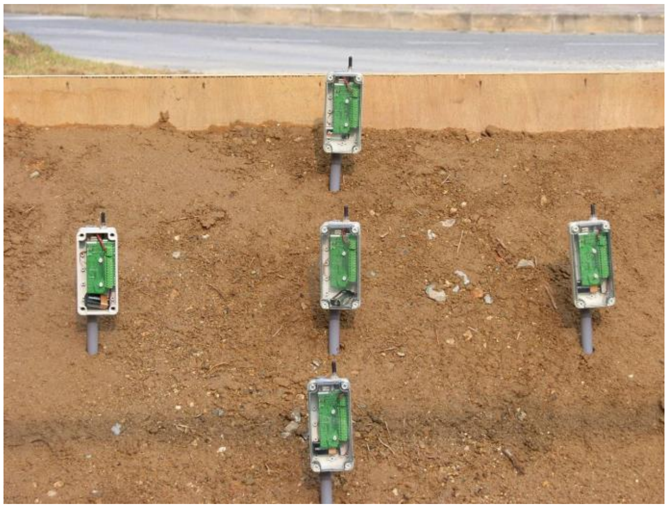
Fig. 1. Photographs of landslide detection sensor node: (a) plastic box containing sensor node; (b) view of PCB.

When the data is ready for communication, the Bluetooth wireless transceiver is utilized. Operating on the ISM (Industrial Scientific and Medical equipment) band, this can communicate with ranges as large as 30 m (line-of-sight). It is found that the maximum power consumption is about 43mA during communication.

C. Experimental studies

In order to verify the feasibility of landslide detection sensor, a series of experimental studies was performed. A small-scale artificial earth slope has height of 0.8m and base of 1.2m (Figure 2a). Geotechnical laboratory tests show that the soil is classified as a silty-sand, and the cohesion is 0.11 kg/cm² and angle of internal friction is 39.7 degree. Five sensor nodes distributed on the slope as shown in Figure 2b, and water supplied by artificial rainfall dropping device to simulate real storms. The rainfall intensity was uniformly set to 30mm/hr, and the test continued until all the sensor nodes turned over completely due to landslide.

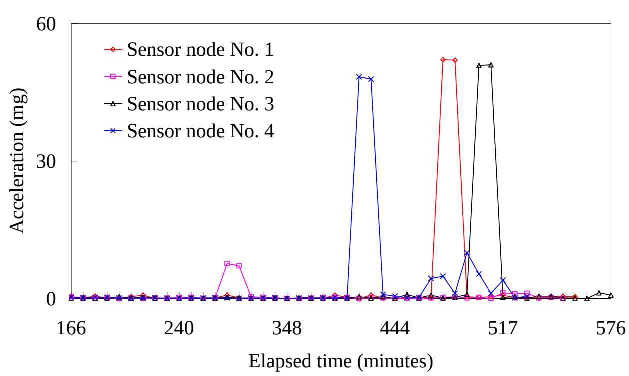
(a)



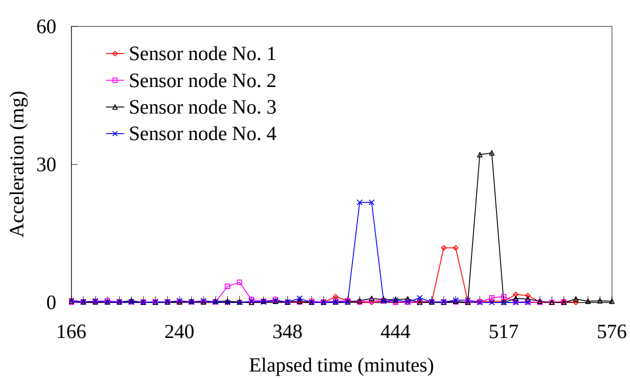
(b)

Fig. 2. Photographs of experiments: (a) view of artificial earth slope and wireless rainfall gauge; (b) array of sensor nodes.

After about four hours, some channels occurred, upper soil is eroded, and granular materials disintegrated and flowed down with water. Simultaneously, the sensor nodes started to incline and move downward slightly. Figure 3 shows x-axis and y-axis acceleration change of each sensor node. Only four acceleration curves are shown because sensor node no. 5 was out of order during the experiment. It is found that the sensor node no. 2 that was installed at the lowest position started to move first and the remaining sensor nodes turned over successively.



(a) x-axis acceleration

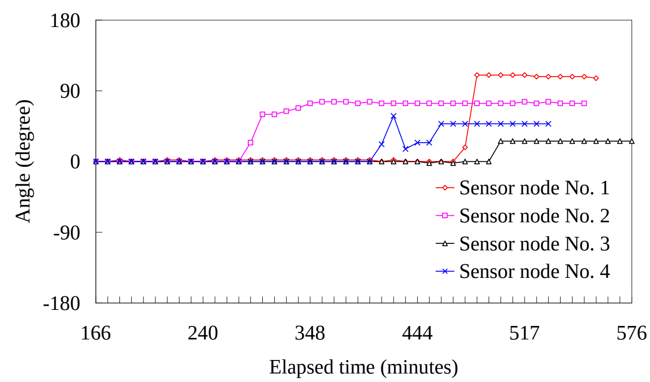


(b) y-axis acceleration

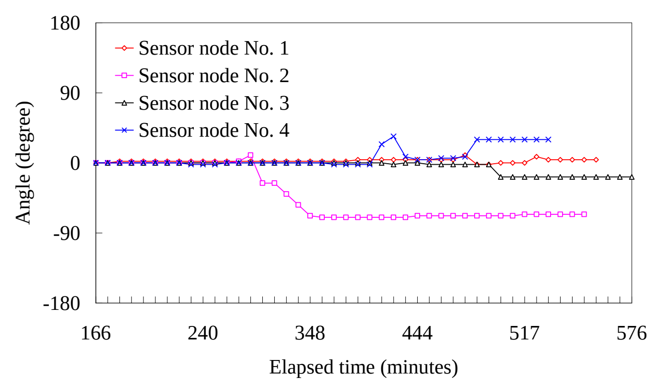
Fig. 3. Acceleration graphs of sensor nodes: (a) x-axis acceleration; (b) y-axis acceleration.

Figure 4 shows x-axis and y-axis inclination angle change of sensor nodes. As previously noticed, it is found that the sensor node no. 2 starts to move first and the remaining sensor nodes are turned over successively. It is also observed that the time of acceleration and inclination change is identical, and from this fact, it is possible to detect ground motion by measuring acceleration and inclination angle. In addition, the magnitude of ground motion can be estimated by acceleration value, and the inclination of slope can be configured by angle data.

It is expected that the landslide detection sensor nodes developed in this study can be applied to the slope where debris flows are likely to happen, because granular materials such as gravels and stones may hit the sensor nodes during debris flow initiation. If the sensor nodes are distributed more densely, the possibility of detecting debris flow will increase higher. Thus, debris flow can be predicted, if the thresholds are predefined according to the slope condition.



(a) x-axis inclination angle



(a) y-axis inclination angle

Fig. 4. Inclination angle graphs of sensor nodes: (a) x-axis inclination angle; (b) y-axis inclination angle.

IV. CONCLUSIONS

In this paper, a prototype of landslide detection by WSN has been described. As information and communication technology (ICT) develops, landslide monitoring systems are becoming more precise and cost-effective. Landslide monitoring system by wireless sensor network will be an alternative to detect and predict slope failure including debris flows. In order to develop the technology, further studies are needed.

It may be difficult to determine whether the slope is stable or not solely using data collected by landslide monitoring because slope stability depends on soil type and soil condition, groundwater table, soil moisture content, slope failure type, rainfall, and vegetation, etc. If the predefined threshold is set too low, there will be too many false alarms, so that genuine warnings will not be heeded. On the other hand, if the threshold is set too high, events that will cause damage may be ignored (miss-alarm). Therefore, it is necessary to predefine the appropriate thresholds to determine the slope stability, and related work is required.

V. FUTURE WORKS

Since this study was performed several years ago, the wireless sensor node for landslide detection has now a lot of room to develop. Recently, wireless communication module has been improved and smart sensor to detect movement has been also developed. Emerging technologies such as energy harvesting, IoT(Internet of Things) and artificial intelligence are now being introduced. If this study is performed again at this moment, current technologies can be incorporated to provide more reliable results. Wireless sensor nodes introduced in this study have been applied to not a real landslide but a testbed, because there are many problems such as short battery life, lack of lightning damage prevention, and lack of validation for issuing alarm, etc. Wireless sensor node to detect landslide, however, are very promising and the technology is likely to develop rapidly over the coming years. To do this work, geotechnical engineer and ICT engineer should cooperate with each other. It is expected that this work will provide a methodology to develop a wireless sensor node for landslide detection.

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